

Next Generation Natural Gas Vehicle Program

Vehicle Working Group
Workshop
May 2-3, 2000
Chicago, IL

Details of Story Board Recommendations and Votes





Workshop Goals

- Give participants a clear understanding of the NGNGV Program
- Provide an overview of existing applicable DOE, GRI, SCAQMD, and CEC research
- Obtain input on the technologies and vehicles that should be developed in the program:
 - Vehicle types and markets
 - Natural gas engine technologies
 - Vehicle fuel system and storage technologies
 - Body and chassis technologies
- Gain early interest and support for the program



NGNGV Vehicle Working Group Meeting May 2 and 3, 2000 in Chicago

Over 40 Participants....

- Original Equipment
 Manufacturers and Vehicle
 Packagers
 - Crane Carrier Company
 - Cummins Engine Company
 - FAB Industries, LLC
 - Ford Motor Company
 - Freightliner Corporation
 - John Deere Power SystemsGroup
 - Mack Trucks Inc.
 - Orion Bus Industries
 - PACCAR Technical Center

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NGNGV Vehicle Working Group Meeting May 2 and 3, 2000 in Chicago

- Fleet operators
 - United Parcel Service
- Industry/ Trade Associations
 - American Trucking Associations
 - Natural Gas VehicleCoalition
- Funding Partners
 - California EnergyCommission
 - GRI
 - South Coast Air QualityManagement District
 - U.S. Department of Energy

- Utilities and Fuel Distributors
 - KeySpan Energy
 - Pacific Gas and Electric Company
 - Southern California Gas Company
- National Laboratories and Research Groups
 - Argonne National Laboratory
 - Brookhaven National Laboratory
 - Idaho National Engineering and Environment Laboratory
 - National Renewable Energy Laboratory
 - Oak Ridge National Laboratory



Workshop Participants (continued)

- Equipment Suppliers
 - CHART-MVE
 - Lincoln Composites
 - Pressed Steel Tank
- Industry Research, Consulting and University
 - Arthur D. Little, Inc
 - ASG Renaissance
 - Battelle
 - BusPlan
 - Institute of Gas Technology
 - Southwest Research Institute
 - The Research Partnership
 - West Virginia University

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Input from the Vehicle Working Group

- Participants divided into four groups to provide recommendations on:
 - Vehicle types and markets
 - Natural gas engine technologies
 - Vehicle fuel system and storage technologies
 - Body and chassis technologies
- Groups rotated such that everyone had input to each topic
- Recommendations where then organized and categorized by participants
- All participants voted to identify most critical issues and technologies

Medium-duty CNG Who are Fleet Customers of Medium-duty CNG Vehicles that may be Good Potential Customers for Vehicles from this Program?

• Mail/Package Delivery (40)

- UPS.
 - o Atlanta, GA
- Federal Express
 - o Memphis, TN
- USPS
 - o National
 - o U.S. Postal Service
 - o Merrifield, VA
- US Express
 - o Chattanooga, TN

• Beverage Delivery(12)

- Coca Cola
 - o Everywhere
- Coca Cola Delivery Companies
- Pepsi Cola Delivery Companies
- Adwalla juice delivery

• **Shuttles (32)**

- Major hotel chains
- Shuttle bus
 - o Dial-a-ride
 - o Municipal
 - o Cal trans
 - o El Dorado
- Tourist "Trolleys"
- Avis
- Airport shuttles
- Commuter buses
- Airport shuttle fleets
- Rental/leasing

• Local Delivery(10)

- Staples (delivery vans)
- Bakery (Entemanns)
- Home Grocer.com
 - o LA Basin
- Ryder Trucks
 - o Lease/rental

• Undefined(0)

- Gas utilities
 - o SoCal Gas
 - o PG&E
- Utilities
- City of Chicago
- Recreational Vehicles
 - o Winnebago, e.g.
 - Insufficient infrastructure in vacation areas
- Consideration of International markets & trade opportunities

• Off-ROAD/SPECIALTY (3)

- Street & parking lot sweepers in SCAQMD
- Truck fleet yard tractors
- Construction
- Agricultural

• School BUSES (9)

• La USD, La Basin







Heavy-duty LNG Who are Fleet Customers of Heavy-duty LNG Vehicles that may be Good Potential Customers for Vehicles from this Program?

• Long-Haul Mail/Package Transport (13)

- USPS National
- UPS
 - o Atlanta, GA
- UPS
- RPS
- Yellow freight

Short Haul Grocery/Food/Goods Transport (34)

- H.E. Butt Grocery o San Antonio TX
- Miller Brewing
- Swift Trucking
 - o 7-8
- Safeway (grocery stores)
- Food Lion Distribution Ctr@
 - o Clinton, TN
- Vons Groceries
 - o Los Angeles, CA
- Continental Bakers
 - o Denver, CO
- Beverage Fleets
- o Soft drinks
- o Beer
- o Water
- Wal-Mart
- Shamrock Foods
 - o Denver, CO

● Long Haul (16)

- Must emphasize high-mileage line-haul trucks, because these will ultimately have the best economics
 - o Various GRI (eg, Zeus) projects show this
 - o Apply "gov" funding to overcome infrastructure challenges (i.e., stations) affecting this class
- Wal-Mart
- Ryder Trucks
 - Rental/Leasing
- Private carriers
 - o (DelMonte, etc., Roley)
 - o (vs. "authorized for hire")
 - o where image counts
 - Contact NPTC
- o Waste/Trash Haulers (26)
 - Waste Management Palm Desert
 - This customer application is also viable for CNG
 - Browning Ferris
 - Waste Management National
 - Heavy-duty refuse haulers and construction vehicles are strong CNG candidates.

• Large Shuttle/Transit Buses (7)

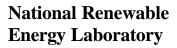
- Airport shuttles
- Montgomery County
- Baltimore
- Transit bus

School Buses (4)

- School bus
- Off-Road (4)
 - Marine vehicles tugboats/barges
 - Mining vehicles
 - Construction/earth moving
 - Rail-switchers

Undefined (1)

- Pacific Bell
- N. California identified (100 fleets) in PG&E market research study







Medium-duty CNG What Type of Natural Gas Vehicle will be most Needed by the Fleets and Most Useable to Them?

• Para Transit/Small Bus (35)

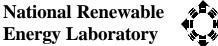
- 28-32 Passenger School bus
 - o Range
- Para transit
- Cutaway
 - o Super duty
- Cutaway
 - o Class 3 & 4
- Hotel/rental car Shuttle
 - o Integrated chassis
 - o Tank placement
 - o (luggage storage)

• Delivery Vehicles (54)

- Pickup & delivery
 - o Range
 - o Performance
 - o Noise
- Delivery truck
 - o Package delivery
 - o Fueling-time &facility
- Step vans
 - o (e.g. UPS & Fed Ex)
 - o 3-6
- Strip chassis & Cab chassis
 - o Fuel economy

• Other (5)

- Street sweeper
 - o Elgin
 - o Cummins 5.9
- Small Straight Trucks & tractors
- General-purpose chassis allowing body builder flexibility
- A Medium-duty LNG vehicle
 - o Range
 - o Re-fueling interval







Heavy-duty LNG What Type of Natural Gas Vehicle will be most Needed by the Fleets and Most Useable to Them?

• Over-the-Road (29)

- Over-the-Road tractor/trailer
 - o Range
 - o fueling
 - power
 - o infrastructure!
- Tractor-trailer
 - o Range
 - o Less wt
 - o Torque
 - o Fuel economy
 - o Emissions certified
- Reliability
- Durability

• In-City-Route Trucks (60)

- Operations with dedicated routes & terminals (regional haul)
- Day cab for short haul
- Para transit
- Transfer (refuse) truck (long haul)
 - o 330-400 HP
 - o 1200-1400 ft/lb torque
- Refuse truck
 - o Integrated chassis
 - o Weight
- Refuse hauler
 - o Competitive w/diesel
 - o 7-8
- Refuse haulers
 - o Performance
 - o School bus

• Off Road (15)

- Tugboat
- Concrete trucks
- Yard shifters





Medium-duty CNG What Incentives will these Customers Need to Adopt New Vehicles. Where are these Incentives Available?

• Life Cycle Cost (38)

- Fast cost payback
- Lifecycle cost
 - o Validated, standardized model for "life cycle cost"
- Fuel economy
- Cost!
 - o Fuel, maintenance initial cost, subsides
- Initial cost same as equivalent diesel
- Financial incentive to offset incremental purchase cost +
 - o (Maryland DOT)
- Hassle free
- Low operating cost to overcome fuel storage and fill costs
- Cost differential rebate
 - o Illinois
 - 0 3-6
- Long term fuel \$ commitment from gas company
- Operating cost incentive
- Long term need BIG fuel price differential
- Vehicle & engine Differential Cost
- Carol Moyer CA
- MSRC LA basin

Tax Credits (31)

- Jeffords/Hatch Bill
 - o .25/gal tax credit on fuel
- Tax credit on fuel used.
- Eliminate of state excise tax on NG
- Waiver of registration fees & State sales tax
- Reduce local taxes
- State policy/incentive
 - o 3-6
- Individual SIP incentives
 - o 3-6
- Individual SIP incentives

• Customer Satisfaction (6)

- Noise reduction
- Lower noise than diesel
 - o At least 10 dba less
- Drivers & neighbors
- Indemnification for lost service/clients
- HOV opportunity
- Image!
- Real world range claims
- Extended fuel system warranty
- Expanded warranty
- Access to service/parts guaranteed over life of vehicle
- Insurance subsidy

Emission Credits (15)

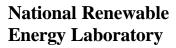
- Emission Credits
- Emission reduction incentives
- Colorado incentive program
- Mobile emission credits
- NOx credits

Mandates (2)

- Regulatory relief
- Fleet rule
- Epact credit
- Punishment avoidance (lawsuits)
- Requirements to use NGVS (AFVs) (re: SCAQMD)

Infrastructure (20)

- Friendly refueling infrastructure
- Infrastructure
- Infrastructure cofunding
 - o CA Energy Comission
- Impoved Safety during Fulling & Operation







Heavy-duty LNG What Incentives will these Customers Need to Adopt New Vehicles? Where are these Incentives Available?

• Tax/State Credits Incentive Programs (32)

- Lower road taxes
- Federal Jeffords/Hatch bill
 - o 0.25/gge tax credit
 - o Tax credit on increm. Price
- 7-8 epact credits
 - o (Energy policy act)
- Regulatory relief
- Fleet rules
- Epact credit
- 3-6 Epact credits
- Vehicle & engine differential tax credits
 - o Carl Moyer CA
 - o MSRC LA Basin
- Waiver of registration fee/state sales tax
- Fuel savings
- Tax credits
- Lower fuel tax
- Tax credit on incremental vehicle cost
 - o Simpler than applying for Moyer \$
- Elimination of State Excise Tax on LNG
- Continue & expand Carl Moyer program in CA
 - o Try to extend to other states
 - o Carl Moyer program was adopted after trying to make mobile emissions credits work)
- Requirements to use NGVs/AFVs re: SCAQMD
- Guaranteed Fuel Availability

• Clean Air Emissions Credit (19)

- Emissions/State Pressure
- Emissions credits
- NOx credits
- Mobile emission credits

• Fuel Costs (30)

- 7-8 long term fuel \$ commitment from Gas Co.
- Cost
 - o Fuel, maintenance, initial cost, subsidies
- Lower fuel cost
- Incremental cost of vehicle
- Emissions based incentives
 - o Maryland/WashCOG Vehicle replacement program
- Tax credit on fuel used

• Customer Satisfaction (21)

- Image
- Image (attracting drivers)
- Guaranteed cost savings (as in Power Gen installations)
- Lower noise level from engine at least 10 dBA
 - o (Driver incentive/late night delivery)
- An LNG training program
- Provide LNG fueling stations for class-8 line-haul trucks
- Infrastructure
- Swat team assistance to help customer identify problem cause (vehicle vs station)
- Life cycle cost
- Certified as ILEV for access to HOV lanes
- Does it take more incentive for a class 7-8 LNG customer than class 3-6 CNG?







Medium-duty CNG and Heavy-duty LNG What Performance Specifications will these Customers Need to Adopt New Vehicles?

Performance

- Diesel-like torque rise (gradeability)
- Consider poor part load efficiency (throttled) before choosing vocation
- Driveability
 - Easy-to drive
 - o Good feel/response
- Easy to use
 - o Idiot proof
- Driveability
 - o Easy to drive
 - o Good feel/response
- Improved fuel economy
- Consider poor part load efficiency of SING in choosing vehicle

• Cost (50)

- Improved fuel economy
- Equivalent fuel use at idle
- Cost of ownership
- Customers are not favorable of dual fuel technology
 - o Cost of maintenance
 - o Drivers complain
 - o Very difficult to sell
- Durability
- Heavy-duty demo should emphasize:
 - o Fuel efficiency
 - o Driving range
 - o Over-the-road usage
 - o Diesel-based engine

Maintenance (17)

- Low maintenance costs
- Safety & cost and cost & safety
- Medium-duty demo should emphasize:
 - o Low cost system
 - o Use gasoline-based engine (cost/wgt saving)
 - o Low emissions (tailpipe & evap)
 - o Low speed usage (city)
 - o "Smaller" engine
- East of fueling
- Reliability

• Other (1)

Operations in environmentally sensitive areas







What Engine Performance Features will be Important to Customers of Natural Gas Vehicles in 2004?

• Durability (5)

- Diesel-like Durability
- Robustness
 - o Altitude
 - o Gas quality
 - o Humidity

• Maintenance (15)

- Better maintainability
- Low maintenance Costs
- ≥ maintenance (e.g. spark plug changes)
- 50,000 mile Spark plugs
- No injector problems

• Oil Compatibility (0)

- Extended oil change intervals
- Smart Diagnostics *on-board diagnostics (2)
- Reliability (1)
- Increased Range (3)
 - High flow, low-pressure injectors for better range

• Fuel Economy (30)

- Fuel economy equivalent to diesels
 o Duty cycle dependant
- Fuel consumption similar to diesel
- Diesel-like Fuel economy
- equivalent idle and part load fuel economy
- Low cost and high mileage performance
- Near 50% thermal efficient engine

Lower Cost (31)

- Lower operating cost than diesel
- Equal fuel economy
- Longer service intervals
- Lower maintenance cost
- Less than or equal to original cost
- Low cost engine-gasoline-based (class 3&4)
- Lower 1st cost

• Lower Emissions (11)

- NOx < 1.0 g/hp hr
- Peak efficiency > 45%
- Low PM emissions
 - o Approaching 0.00
- Low emissions
 - o 0.5 gm NOx
 - o 0.01gm PM
- Low leakage injectors to meet tier II evaporative requirements

• Engine Packaging (1)

- Less heat in engine compartment
- Integrate engine electronics with fuel control

• Fuel Quality (1)

- Ability to adapt to off-specification (low quality) fuel
- Utilize a wide range of fuel composition
- Capability to operate on range of fuels (engine)
 - o ≥ 88% CH4
 - o $\leq 8\% \text{ C2} +$

Other (2)

- Accommodate "non-lubed" fuel L/CNG
- Injectors that do not require oil in gas
- Injectors that are tolerant of oil in gas
- Injector systems reliability & durability

• Driveability & Performance (15)

- Driveability,
 - o power, torque, low end torque
- "Matched" engine-transmission-drive train
- Diesel-equivalent driveability, torque, & power
- "Diesel-like" gradeability (i.e. torque)
- Torque Rise
- Idle & full load performance
- Performance equal to or better than diesel
- Power density and torque acceptable for vehicle application
- Easy cold weather starts
- Is throttle a good enough retarder (as Jacobs brake substitute for Class 8 line haul)
- Engine performance goals must be relatively success-oriented. Goals that re too conservative will produce a boring program that will not receive continued funding.







What Engine Technologies should be Incorporated into Leading Edge Vehicles in 2004? Combustion Types

• DING (21)

- Advanced DI NG
- High pressure direct injection
- Direct injection capability for natural gas
- Demonstrated @ steady state
- High pressure cryogenic pump
- Cryogenic pump development
- Fuel injector pump development
- Late-cycle direct injection..
 - o Dedicated NG if suitable low Cetane tech. Emerges;
 - o Dual-fuel (pilot) if not
 - o Barriers are well-resources
 - o R&D underway
- Non-diesel pilot direct injection, e.g., w/glowplugs

● HCCI (0)

- Homogeneous charge compression ignition (HCCI)
- Limited steady state tests on NG production on diesel
- High load/transients/fuel properties
- Variable load combustion development

• SING (18)

- Ultra-lean burn SI
- Advanced SING

Rich burn with EGR (17)

- Stoic NG combustion for low emissions with after treatment
- Stationary NG engines lower durability
- Higher temperatures
- Engine & after treatment development
- Consider spark ignited stoichiometric w/3 way cat for ultra low emissions (but poorer efficiency)
- Stoichiometric w/high efficiency (very low emissions)
- Production/efficiency low
- Fuel economy/EGR tolerance
- EGR tolerant combustion

• Micro-pilot Ignition (4)

- Laboratory Preproduction
- Injector/combustion-Part Load
- Transient Engine Development

• Direct Injection Stratefied Charge (0)

- Production for Ga soline
- Injection life/Disc specific combustion chamber
- Injector DAD Combustion system development
- Prechamber ignition (0)







What Engine Technologies should be Incorporated into Leading Edge Vehicles in 2004? Combustion Strategy

- High BMEP capable (1)
 - o Diesel-like
 - o Lean combustor
 - Miller-cycle engine enhancement
 - Variable CR
 - Knock tolerant combustion (SING)
 - o Production (gasoline)
 - o Commitment for gas products (i.e. customers)
 - o NG specific cylinder heads
 - Regenerative intake air cooling (LNG)





What Engine Technologies should be Incorporated into Leading Edge NG Vehicles in 2004? Other Technologies

- Full electronic controls (6)
 - More accurate fuel metering
- Fuel or A/F ratio sensors for engine control (2)
- Knock sensing (0)
- Advanced spark/ignition systems (0)
 - Skip-fire
 - EGR sensor
 - o May help control engine performance
 - o EGR
 - o Gasoline & diesel
 - o Engine combustion system
 - EGR not required with after treatment
 - o Lean NOx
 - EGR
 - o Limited steady state data
 - o Controls
 - o Develop control strategies/hardware

- Minimum change to the diesel platform (0)
 - EGR
 - After treatment
- Advanced diagnostics (3)
- Fuel composition detection/adjustment (7)
 - Low cost
 - Btu
 - Methane
 - Ethane
 - Propane
 - Inerts
- Hotel load management w/engine off (3)
 - Anti-idling using aux. Power supply for heating/cooling (for long haul)
 - Auto stop/start to reduce idling
 - Don't forget cooling fan loads in considering vehicle (not engine efficiency)
 - Reduce cold-start emissions

- Advnced turbo charger (0)
 - Durable turbo charges
 - Turbo machinery optimum for gas engines
- OBD (0)
- Speed density 3-way catalyst fuel systems (5)
- Durability/Reliability
 - Improve oil control technologies (6)
 - Develop economic durable spark plugs for N.G. engines (1)
- Not Yet Defined
 - Low NCET pressure required to maximize utilization of fuel storage (6)
 - LNG high pressure vs low pressure issues
 (3)
 - CNG lower inlet valve pressure to utilize all fuel in tank or pressure boost pump







What are Current Engine Development Projects that the NGNGV Program Should "Piggyback" on?

- Advance Reciprocating Engine Systems (12)
 - Stationary
- HCCI combustor (3)
- SI & CI
 - Advanced controls diagnostics (1)
 - 0.5 gm Nox/0.01 pm ACMD proposal (9) o Cindy Sullivan
 - Larger, lower cost CNG injectors, with lower sensitivity to fuel quality (lack of lubricity) (20)
 - o IMPCO developing a candidate
 - DING (4)
 - Skip-fire

- Spark Ignited
 - Enhanced efficiency (32)
 - o High efficiency HD NG engine development program
 - Individual engine development (4)
 - o DDC (Deere) Cummins (Mack)
 - o 2.5 -> 2.0 -> 1.5
 - SULEV emission level engines are in production for class 3 (1)
 - o Ford 5.4L V8
 - Baytech ULEV (4)
 - o GM 5.4 & 6.0L engine

- Compression Ignition Dual Fuel, Include Micropilot
 - Westport pilot injection (11)
 - o HPD1 development program, which is primarily company (not government funded)
 - Micro-pilot ignition (4)
 - o Clean air partners/BKM
 - Electronic Fuels Controls, Inc.
 - o Navistar dual fuel engine development







What After Treatment Devices Should be Investigated for NGNGV(s)?

Other Controls

- HDNG after treatment (0)
 - R&D should be integrated with (not separate from) NG engine R&D ... and be as required to meet emissions goals
- Catalyst protection from contaminants (sulfur) (28)
 - Research underway
 - Time +
 - Testing on NG (as opposed to diesel) engines
- Hythane (1)
 - Adding H2 to NG extends lean limit to reduce NOx

• Lean NOx Catalyst (32)

- Lean NOx adsorber
- After treatment for lean combustion
- Low NOx CAT
- Lean burn engine with lean NOx CAT
 - o Lean burn engine with lean NOx CAT not available heat engines available
 - o Successful catalyst
 - o Catalyst development
- Lean NOx catalyst for NG
 - o Current work focus on diesel
 - o Emphasis on diesel business
 - Access effectiveness of experimental lean NOx diesel catalysts/identify others

• Total HC Reduction (28)

- Consider hydrocarbon emissions reduction too – in 4 yrs CH4 will be watched as a greenhouse gas
- CH4 oxidizer
- Oxidati on Catalyst(9)
 - Durable oxidation catalyst to achieve 0.01 pm over engine's useful life
 - o Has not been a target in the past
 - 3-way catalyst
 - o Gasoline & NG stoie eng cats.
 - o High temps of combustion
 - o Engine & CAT durability
 - Aldehyde control
- SCR (SRC) (3)
 - Selective reduction CAT for 0.5 g/NOx
 - Diesel teen- used in EEC
 - Cost & additional fluid storage
 - Development for lean NG engine
 - Urea? It would work!







Medium-duty CNG What Fuel System & Storage Features will be Important To CNG Vehicles in 2004?

Safety

- On-board monitoring of CNG cylinder integrity (23)
 - o "active" system not needing periodic monitoring.
 - o On-board inspection
 - o In-use, real time inspection
 - o On board testing?
 - o Smart tank technologies:
 - o # of fill cycles
 - o surface damage detection
- NDE of used tanks (1)
- Leak Detection (0)
- Accessibility for inspection/removal (0)
- On-board protection against over pressure(0)
- Fail-safe fuel Shutoff at tank Triggered under accident condition
 - o Already in production

Durability

- Longevity (5)
 - o longer life of components & features
 - o Durability/reliability
- Fuel tank robustness (3)
 - o not affected by environment, impact damage, fuel composition etc.
 - o Integrated protection against impact damage to containers
 - o Standard validation test

Smart Fueling

- Temperature compensated fueling system to get full fill (16)
 - o Temperature -compensated full fill
 - o Reduced-temperature quick fill
 - o System sized to accommodate a fast fill of no more than 5 minutes duration
 - Too long
- Accurate metering (11)
 - o Accurate quality in the tank
 - o Fuel station maintenance and cost
 - o Vehicle time to fill requirement
 - o Smart filling vehicle and station communicate fill under all conditions
 - o Combine with fuel composition sensoring in station
 - o Maximize storage volume for range
- Filling operation simplify & speed connections @ fill stations (3)
 - o "User Friendly" fueling.







Medium-duty CNG What Fuel System & Storage Features will be Important To CNG Vehicles in 2004? (continued)

• PRD/Component Improvement

- Manifold PRD vent system with ability to drain water(2)
 - o Simplified standard guidelines for PRD vent systems NFPA 52
 - o Eliminate PRD vent systems.
- Zero failure PRD (3)
 - o More reliable/longer life PRDs
- Durable high pressure regulators (1)

• New Tank Concepts

- Have a diesel saddle tank look (0)
- Conformal tank designs for small vehicles (0)
 - o LNG will dominate truck market
- Torroidal tank for improved packaging in "flat" spaces (0)
- Low pressure (500 psi) storage technology (6)
 - o Adsorbed natural gas (ANG) with comparable storage density to CNG @ 3600 psi
 - o Cost savings 500 psi versus 3600 psi
 - o Adsorptive gas storage

• Lower Weight (3)

- Light weight
 - o Low-weight Fuel storage Module
 - o $\sim .15$ lb/cc ft
 - o minimize weight
 - o < .1 lb/SCF

• Higher Capacity

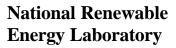
- Improved Volumetric Efficiency (5)
 - o Max. capacity
 - o Compact Fuel Storage (Packaging)
- Consider larger & fewer tanks for improved cost and weight efficiency (4)
 - o 20+ "diameter ≥ 80 " long
- Operating pressures higher? (0)

• Evaporative Emissions (2)

- "Zero"-evaporative emissions
 - o Vent-managed regs
 - o No-leak fittings
 - o No container permeability
 - o Satisfy carb/EPA evap. Std.
- Low permeability flexible fuel lines to meet Tier II evaporative emissions
- Minimize leak points throughout storage system

Defueling

- Easy/safe/emissions friendly
- Defueling
- Defueling system
- Develop workable and safe system to defuel cylinders without venting to atmosphere.







Medium-duty CNG What Fuel System & Storage Features will be Important To CNG Vehicles in 2004? (continued)

Lower Cost

- Lower-cost containers (21)
 - o significant portion of system cost
 - o material cost ~50% total, so less (thinner wall) needed
 - o Low cost tanks <\$.90/SCF</p>
 - o Low cost
 - o Cost
 - o Develop lighter weight and more economical Type 3 cylinders.
 - o Reduced cost tanks
 - ≈ \$.50/SCF
- Lower cost brackets (0)
 - o Mounting Systems
- Low cost high pressure Ancillaries (1)
 - o Lines
 - o Terminal
 - o Valves
 - o Sensors
 - o PRDs
 - o Simple
 - o less fittings
- Modular design (4)
 - o "Pop in/Pop out" for maintenance/replacement
- Cost Reduction on PRD Systems (0)
 - o Low Cost PRDs

Misc

- Fuel gauge that reads tank/cylinders correctly (0)
 - o Still looking for one
- Standardized components across platforms/OEM's(0)

Integration

- Integrated vehicle/fuel system/storage design (1)
 - o Fuel system/storage design
- Integrated storage modules (3)
 - o container brackets
 - o fuel lines shields
 - o valves sensors
 - o PRDs
 - o Tank mounted
 - o Valve protection
- Low pressure fuel lines (1)
 - o i.e. regular at tank to operating pressure
 - o In tank Solenoid & Regulator
- Low cost integrated heat exchanger for 3600 psi systems







Heavy-duty LNG What Fuel System & Storage Features will be Important to LNG Vehicles in 2004?

• Tank integrity (4)

- Vehicle fuel tank to outlast the engine with only routine maintenance
- Vacuum/fitting integrity
- Tolerance to overroad vibrations
 - o Std needed

• Low-cost tanks (14)

- Lower cost tanks
- Lower cost
- Lower cost tanks
- Standard size tanks

On-board accurate fuel gauge (11)

- System to gauge fuel level under varying conditions
- Fuel quantity
- Accurate fuel gauge
- On-board, linear at low tank level

• Tank defueling (7)

- Tank defueling capability
- Defueling system for LNG vehicles for emission, safety and fuel recovery T.
 Barker
- Easy/safe/emission friendly defueling

• System Integration (14)

- Ability to fuel multi-tank systems completely & quickly
- "Systems" designed fuel system
 - o Pipe diameters
 - o Correct size heat exchangers
 - o Multi tank manifold
- Compact fuel storage (packaging) energy density & volumetric efficiency
- Ability to store fuel on vehicle at low pressure & high density
- Ability to manage fuel tank pressure
- Maintain low storage pressure while providing "high" fuel rail pressure
- Avoid pressure building in tank and venting of CH4
- Vehicles designed to accept cylindrical tanks
- Low cost more efficient heat exchanger

• Safety-CH4 Detection (3)

- Odorized LNG
- High Pressure Engine Fuel Pump (4)
 - Reliable high pressure fuel pump for vehicle
 - Capability of providing 3000+ psi NG to support late-cycle DI engine requirements
- LP Storage Maximize Energy Density (18)
 - Lower LNG pressure (colder)
 - Need low pressure fuel metering system as enabler
 - o Yes! Nice one integrate storage + fuel system (engine concepts)
 - Ability to relieve LNG station of fuel "preconditioning" requirement
 - Low pressure (~20 psi) storage pressure
 - Lower pressure maximizes







Heavy-duty LNG What Fuel System & Storage Features will be Important to LNG Vehicles in 2004? (continued)

• Venting Management (15)

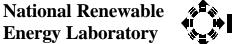
- Tolerant of long times between refueling
- Boil-off management
- Low permeation fuel lines, fittings and diaphragms for Tier II evap emission requirement
 - o Will evap be methane or just NMOG?
- Controlling LNG boil off
- Minimize evaporative emissions
- Vent gas neutralization
- Reduce losses during refueling and nonuse
- More effective, light weight insulation
- Low weathering loss for improved range, and fuel composition (to engine)
- Zero leak to atmosphere
- LNG evaporative losses
- Adsorptive traps

• Standardize Receptacle – User-Friendly (21)

- User Friendly
 - o No protective clothing
 - o No leaks /spills
 - o Easy connection
 - o Light-weight/easy to handle
- Compatible fuel nozzle receptacle
- Automated fueling
- Anti-splash provisions for receiving safely
- User friendly dispense
 - o (so you don't have to hit the nozzle w/a hammer to get the ice off.)

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- Complete treatment of fueling safety issues
- User friendly fuel system
- No self-serve fueling on line
- 1 vs 2 hose systems
- Safety during filling operation







Medium-duty CNG

What are Current Fuel System & Storage Development Projects that the NGNGV Program Should "Piggyback" on?

• Cost Reduction (35)

- Reduced-cost CNG storage, such as high-strength Steel
 - o PST
 - o Faber
 - o Norris
- GRI/DOE improved Type IV development study
 - o GRI
- Lower-cost type 4 container
 - o Lincoln composites
- Low cost mfg process for all type high pressure tanks
 - o All tank manufacturers
- Low cost Type 3 container
 - o PST
- Large diameter tanks
 - o 20"
 - o PST
- High Strength Steel/Aluminum Container Development, GRI
- Multi shield, All composite tanks, Calstart

System Safety (22)

- Acousto ultrasonics for on-board damage sensing, Battelle
- Impact damage sensing coating, Battelle
- Leak prevention & detection, SAE
- Fuel Control & Piping (26 3/4)
 - Improve system component selection
 - o Fittings
 - o Valves
 - o Relief devices
 - Low-cost, impact resistant fuel line terminals.
 - Low-cost Combination PRDs
 - Integrated pressure regulator and tank valve for reduced cost, simplification and improved safety/emissions. IMPCO,
 Veritek and GFI have projects.
 - Reliable pressure regulators
 - Single & dual stage
 - Robost, high flow, Positionable tank valves
 - GRI Systems Integration, Recommended guidelines for designing & installing fuel systems, Battelle
 - Improve multitank manifolding, FAB
 - Low cost, compact automatic tank valve (solenoid).

• Volumetric Efficiency New Concepts

- Thiokol conformable tanks, Thiokol (2)
 - o APL/JHU ISS (Integrated Storage Systems) Project,
- Low pressure (adsorbed) fuel storage, ORNL (6)
 - o DOE OTT heavy vehicle systems
 - o ORNL adsorbed natural gas technology (500 psi)







Heavy-duty LNG What are Current Fuel System & Storage Development Projects that the NGNGV Program Should "Piggyback" on?

• Liquefier Projects

- Small scale liquefaction (6)
 - o Cryofuels systems
 - o Small scale liquefier IGT
 - o Low pressure
- Small scale liquefaction (10)
 - Pacific Gas & Electric
 - o Small scale liquefaction
 - o Southern California Gas Co
 - o Pressure let down
- Small scale liquifier (0)
 - o Thermo-acoustic
 - o Cryenco/Chart

• On-Board Pump and Pressure Build Projects

- Ineel's 2001 development of an advanced economizer that maintains low tank pressure while providing "high" pressure to fuel rail (12)
 - o Pressure building device for fuel tanks
 - o IWG-Ineel
- LNG pump technology (25)
 - o Westport
 - Brookhaven
 - o High-pressure Liquid + vapor Pump Dev.
 - [DOE-BNL program]
 - o LNG vaporizer driven LNG pump technology to enable:
 - o Storing low-pressure high density LNG in tank
 - o Providing NG to engine at any needed pressure (100-3000+ psi)
 - o Managing fuel tank vapor pressure
 - o DOE BNL program underway

• Low cost stations projects (21)

- Low cost fuel station, INEEL
- Low cost fuel station, Chart

• Tank Development Projects (10)

- Non-weathering tank, Chart
- Low pressure LNG storage Tank, BNL project

• SAE/IWG Projects

- Odorized LNG (5)
 - o IWG-SAE fuel composition
- Standardized receptacle for fueling (2)
 - o IWG & SAE –
- Weights & measures certified metering (10)
 - o SAE LNG task force, Chart
- NGV-IWG LNG task force for station/Vehicle compatibility (0)
- Precise fuel metering (0)
 - o Weights & measures approved meter for retail sales







Medium-duty CNG What Vehicle Body Developments that are Ready Now, or will be Ready by 2004 should be Incorporated Into the Medium-duty Prototype Vehicle?

Design

- Our vehicle should look just like "conventional" vehicle EXCEPT for NG fuel system (12)
- Consider/Assess All existing designs (5)
 - o FCC bluebird
 - o Use a recently introduced cab suitable for the selected application (recent as a 2004)
- Provision for tank location (CNG) which do not require pro vent lines (medium CNG) (6)
- Design body to accommodate conformal tanks and large after treatment devices (but allow for tank inspection)(23)
 - o Design to accommodate large DIA tanks for improved cost/wt.
- Medium-duty paratransit bus (16)
 - o Low floor
 - Roof mounted CNG tanks
 - o Low entry for driver
 - o Body/Chassis Design
 - Designed exclusively for CNG vehicle, not diesel-based with "bolt on" CNG system. For example – new approach for placement of storage system to give better maintenance access. Make unique needs of CNG an integral part of body/chassis design.

Materials

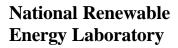
- Use lightweight materials (4)
- Light weight tanks (1)
- Extensive use of light weight composites and aluminum (1)

Safety

- Tank safe design accessible for safety inspector (3)
- Design for crash worthiness (0)
- Use structural integrity of storage tank to minimize/reduce weight of chassis/body (9)
 - o Comment frames are designed to flex.

• Features/Other

- Ask the customer! (13)
- Cab temperature management glazing; insulation; PV-assisted ac/heater (3)
- Incorporated aerodynamic features for efficiency and to emphasize forward thinking design (1)
- Instrumentation (1)
- Ergonomics (0)







Medium-duty CNG

What Vehicle Chassis Developments that are now Ready or will be Ready by 2004 should be Incorporated into the Mediumduty Prototype Vehicle? (continued)

• Chassis Technology

- Current state of development
- Types of vehicles for which the technology is applicable

• Intelligent Vehicle Systems

- CAN Buss (2)
 - o Communications for chassis, engine, trans
- Vehicle self diagnostics (4)
 - o Smart vehicle that communicates problems

Cost

- o OE
- o Maintenance
- Class 3-6 mid-range chassis cost (2)
- Maintenance cost cannot exceed diesel maintenance cost (9)

Stay where you are

 Our vehicle should look just like "conventional" vehicle except for NG fuel system (19)

Cats & Dogs

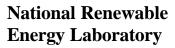
- Possible integrated body & chassis for Class 3&4 (1)
- Increased weight carrying capacity (3)
- Class 3-6
- Fuel Fill time 5 min or less (11)
 - o Equal fuel capacity to present diesel
- Consider "lessons learned" from past other NG product development efforts i.e. USPS
 2-ton truck project (2)
- Provide an integrated vehicle test prior to placing prototype in service (1)
 - o "Work the bugs out"
- Run flat tires (0)
 - o more space for CNG tank
- Cut away (12)
 - o Cut away chassis for shuttle vehicle
- Continuously variable transmissions (CVT) (11)
 - o Can be used to make up for fuel economy penalty with NG allows engine to operate under limited range

Design Vehicle for NG

- Incorporate container "strength" into chassis design (0)
 - o Concerns about tank integrity
- Chassis can be different to accommodate fuel storage without affecting body appearance (0)
- Vehicle design able to accommodate low pressure adsorption for storage (2)
 - o Assume this technology won't be ready by 2004.
- Utilize voids in body to "fit" fuel storage (14)
- Provide large, unobstructed spaces for mounting the fewest large tanks (17)

Frames

- Use tank structure to transfer crash impact loads to reduce shield lost weight (6)
- Use aluminum in frame components to save weights (3)
 - o Cost penalty
- Lightweight frames (1)
 - o Low pressure storage @500 psi integrated into Chasis/frame
- Hydroform (2)
 - o Frame components for light weight & strength







Heavy-duty LNG

What Vehicle Body Developments that are Ready Now, or Will be Ready by 2004 should be Incorporated into the Heavy-duty Prototype Vehicles?

Body Technology

- Current state of development
- Types of vehicles for which the technology is applicable

Design

- Use a recently introduced cab suitable for the selected application (recent as of 2004) (2)
- Build refuse trucks (5)
- Better vent design to avoid water intrusion
 (0)
- Watch 21st Century truck program (1)
- Our vehicle should look just like "conventional" vehicle except for NG fuel system (3)

Fuel System

- Body & chassis features that accommodate any LNG tank and fuel system standards promulgated by SAE or other ora l. (e.g: tank shields or shrouds) (16)
- Design to accommodate fuel tank(s) (not an after thought) (32)
- Chassis OEM integrate fuel system (0)
- Relocate battery box to allow for longer LNG tank to replace existing diesel tank
 (0)
- Greater fuel storage quantities(4)
- Design for FMVSS crash testing worthiness (0)
 - o Comment consider drop-test of tank, like diesel tank
- On-board methane detection system that has low current draw and is reliable (4)

Features

- Need to consider underhood cooling carefully if using novel aerodynamic design (1)
- Anti-idling (19)
 - o Using AUX power for cab power, heating & cooling to reduce vehicle engine (class 7/8, long haul)
- GPS, Global positioning (0)
- CAN communications for chassis, body, trans engine (1)







Heavy-duty LNG What Vehicle Chassis Developments that are Ready Now, or will be by 2004, should be Incorporated into the Heavy-duty Prototype Vehicles?

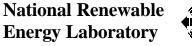
• Stay where you are

• Our vehicle should look just like "conventional" vehicle except for NG fuel system (14)

Motherhood

- Involve the customer (always) (6)
- Chassis OEM be willing to build a truck w/NG engine (15)
- "Piggyback" 21st Century truck (2)
- Revised max weight laws so that any extra weight of NG storage & engine components do not penalize truckers' payload capacity(3)
- Incorporate as many existing and advanced tech. W/o investing program R&D funds on non-NS advancements (5)
- Provide an integrated vehicle test prior to placing prototype in services (1)

 (27)
 - o "Work the bugs out"







Other Ideas and Issues for Body and Chassis Technologies

Tanks

- Advanced LNG tank protection for crash (11)
- Allow for larger diameter LNG tanks to replace existing diesel (4)
- Incorporate fuel tanks within frame for crash protection (3)
- Lower cost storage options (3)

Tires and Brakes

- Improved brakes (0)
- Low rolling resistance tires (0)
- Super single tires (0)
- Design chassis to accept retarders or is throttled engine braking enough? (1)

Other

- Improved aerodynamics, CL.7/8 (0)
- Natural gas, auxiliary power, unit (no engine idle) (9)
- Advanced cooling system components (13)
 - o Radiator
 - o Electric water pumps
 - o Nano-fluids?
- Greater cooling system capacity to accommodate advanced emissions controls
 (2)
 - o Such as 3-way catalysts & EGR
- Drive line optimization better integration with a NG engine torque curve (12)







Parking Lot

- Fuel quality issues
 - did not see it covered anywhere (see SAE LNG task force)
- Heavy hybid
- Vehicle demo for potential customers
 - No blind faith
- Safety
 - No leaks
 - Ease of detection if leaks do occur
 - Reputation of safety
 - User friendly fueling?

- Need basic research to continue or NG will get behind diesel and others even further!
- Warranty 100,000 200,000 miles on all components, Medium-duty
 - Higher on Heavy-duty
- Integrated chassis/fuel system warranty
- Do market research?
- Rental/Leasing
 - Can't trust the public yet!
 - Must be hassle free to get rentals by 2004
- Get customers onboard-visit

- What is commercial viability?
 - # of vehicles
 - Define criteria
- Market studies
 - GRI
 - PG&E





